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INVESTIGATION OF AIR FLOW IN RIGHT-ANGLE ELBOWS

IN A RECTANGULAR DUCT

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WASHINGTON

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INTRODUCTION

The increased complexity of modern airplane-engine installations, with extensive use of duct systems, has greatly increased the importance of well-designed bends in ducts. The improper functioning of aircraft carburetors, for instance, has been blamed in many cases on the poor ducting of air before it reaches the carburetor. Among the major faults found in the ducting systems is the improper design of elbows just before the carburetor.

The original purpose of this investigation was to obtain an elbow shape for use in airplane carburetor air intake ducts, which has low losses and good velocity distribution without the use of turning vanes. This investigation was not intended to be a complete study of duct elbows, as its scope is limited to elbows of proportions which were considered to be most practical.

APPARATUS AND METHOD

The tests were conducted using a rectangular duct having a width, w, 2.57 times as great as the depth, d, and having the elbow in a horizontal plane. This ratio, w/d, which will be called the aspect ratio of the duct, was chosen since it is applicable to the carburetor for a modern airplane engine. Other proportions, which are shown in figure 1, were chosen as likely proportions in engine installations.

The tests were made at a Reynolds number of about 200,000, based on the depth of the duct, which was 2.625 inches. An entrance length of about nine times the duct depth was used to build up a boundary layer approximating conditions in an actual installation.

The air was drawn through the duct by a blower mounted in the rear of the entrance tube and elbow. This allowed

the entrance tube alone to determine the type of flow and amount of boundary layer.

A rake measured the static and total pressure distribution across the depth of the duct back of the elbow. The location of the rake was chosen at 2.88d back of the center line of the entrance ducts on all entrances except K and L. (See fig. 1.) This location was considered to be a practical location from the standpoint of actual duct installations. Moving the rake either forward or backward would, of course, change the measured pressure drop and the velocity distribution.

Behind the rake the tube was continued for a distance of twice the depth before the air was discharged into a large tube in the blower. The length of this tube was sufficient to assure the complete turning of the air. An extremely short tube following the bend would have allowed the air to leave the tube before the air was completely turned.

The two characteristics of the elbows which were considered to be important were the amount of flow for a given pressure drop and the velocity distribution across the duct after the bend.

RESULTS AND DISCUSSION

The results are presented in the following nondimensional units:

$$F_c = \frac{Q}{A\sqrt{\dfrac{2(\bar{p}_1 - \bar{p}_2 + \bar{q}_1)}{\rho}}} \qquad \text{flow coefficient}$$

$$\frac{V_2'}{\bar{V}_2} = \sqrt{\frac{q_2'}{\bar{q}_2}} \qquad \text{velocity ratio}$$

x/d distance from inner wall in terms of duct depth at rake section

ρ mass density of air

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and the following dimensional units:

$P_0 - P_2$ static-pressure drop in both entrance duct and elbow

$H_0 - H_2$ total-pressure drop

where

Q quantity of air, cubic feet per second

A cross-sectional area of duct at rake

P_0 free-air static pressure, inches of alcohol

P_2 average static pressure at rake, inches of alcohol

$\bar{p}_1$ average static pressure at the beginning of the bend, pounds per square foot

$\bar{p}_2$ average static pressure at rake, pounds per square foot

V_2' velocity at any point across stream at rake

$\bar{V}_2$ average velocity at rake section

$\bar{q}_1$ average dynamic head before the bend, pounds per square foot

q_2' dynamic head at any point across the stream at the rake, pounds per square foot

$\bar{q}_2$ average dynamic head at the rake section, pounds per square foot

H_0 free-air total pressure

H_2 total pressure at any point across rake section

x distance from inner wall at rake section

d depth of duct at rake section

The flow coefficient, which was devised to show the effectiveness of the elbow, is the ratio of the quantity of flow through the actual turn to the quantity of flow through

an ideal duct with the same static-pressure drop, the ideal duct being one in which all the static pressure is converted into velocity head. The static-pressure drop in the actual elbow was considered as being the drop due to losses in the bend plus the drop due to the velocity head. When the losses through the elbow are zero, the flow coefficient is unity. If the effectiveness of the duct were to be based on the total-pressure loss, unsatisfactory results would be obtained, as the loss of pressure is almost negligible and most of the reduction in quantity is due to uneven velocity distribution rather than total-pressure losses.

The values of the flow coefficient F_c for the various ducts are presented in the following table:

TABLE I

Elbow	Ideal elbow	A	B	C	D	E	F	G
F_c	1	0.937	0.837	0.840	0.840	0.852	0.898	0.881
Elbow	H	I	J	K	L	Straight duct		
F_c	0.914	0.836	0.930	0.930	0.956	0.984		

Since the velocity distribution is of considerable importance, especially for bends in front of carburetors, the velocity distributions are presented in figures 2 to 5.

Figures 6 to 18 are the plots of the total-pressure and static-pressure drops across the entrance duct and elbow, measured at the same.

DISCUSSION

The advantages of the well-rounded corner over the square outer corner are clearly shown in table I, and in a comparison of figure 2 with figure 3. The flow coefficient of duct A, which is about 10 percent higher than that of any of the square outer corner bends, is conclusive proof of the lower loss of ducts of type A of these proportions. The

velocity and pressure distribution are also much better for duct A than for ducts B, C, or D.

These data do not agree with the conclusions arrived at in reference 1, apparently because the invalid assumption was made that the losses of the two elbows would maintain their relative values when the aspect ratio and other proportions were changed from those tested. This assumption need not be true as the losses of the two elbows may be entirely different in nature and, therefore, be affected differently by the duct proportion. Therefore, although the elbow with square outer corner was found better at low aspect ratio than the well-rounded corner (reference 1), it does not follow that the square outer corner was also better at high aspect ratios.

The accelerating ducts E to K, inclusive, were designed with the idea of improving the air flow by creating a favorable pressure gradient through the elbow by accelerating the air as it rounds the corner. Unfortunately the losses in expanding the air back to the original area are generally greater than the decrease in loss through the bend.

Bends F and G were attempts to overturn the air in order to reduce the boundary layer on the inside wall. (See reference 2.) Elbow G succeeded in reducing the boundary layer on the inside wall even below that of elbow A, but the losses were considerably greater than those of elbow A. Another means of reducing the boundary-layer thickness on the inside wall and making the flow more nearly symmetrical was to make the whole expansion on the outside wall, leaving the inner wall straight after the turn. Elbows H, I, and J are versions of this. Elbow J was considerably better than elbows H and I. This elbow had a better velocity distribution than elbow A, with only a slightly lower flow coefficient.

The characteristics of elbows K and L are not quite comparable with those of the other elbows, as the cross-sectional area at the entrance was greater than that of the others. Elbow L is actually a version of the accelerating elbow, except that there is no expansion after the turn. This elbow is considerably better than any of the others tested, since it has all the advantages of accelerated turn without the disadvantage of an expansion. Unfortunately this type is seldom practical, as it requires a reduction in the cross-sectional area of the duct through the elbow.

The elbows A, J, and L, which were the best of those tested, are not necessarily the best elbows that can be made. Several changes can be made on elbow A, which would increase the flow efficiency. Increasing the radius has been shown to decrease the loss (reference 1). Increasing the aspect ratios, the width divided by the depth, has also been found to decrease the losses. (See references 2 and 3.)

The value of guide vanes in ducts of these proportions is doubtful, since the main value of guide vanes is in bends of very low aspect ratio or where very sharp bends are required. When good proportions can be used in the elbow, the losses are so low that very little, if anything, can be gained by the use of guide vanes.

CONCLUSIONS

1. A well-rounded elbow with aspect ratio of 2.57 had considerably lower losses and better velocity distribution than one with square outer corners of the same proportions.

2. An accelerating elbow of one type resulted in a better velocity distribution beyond the elbow than any of the other elbows tested having the same entrance and exit duct areas. This was accompanied by only a very slight increase in loss.

3. An accelerating elbow having a smaller exit duct than entrance duct was found to have the lowest losses of any tested.

4. Although these tests indicated that certain elbows were superior aerodynamically to others, there is no proof as yet that they will provide better carburetor operational characteristics; in fact, reports to the contrary are prevalent. The work that is continuing along these lines should do much to clarify many unknowns that now exist in the application of duct design.

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3. Patterson, G. N.: Note on the Design of Corners in Duct Systems. R & M. No.1773, British A.R.C., 1937.

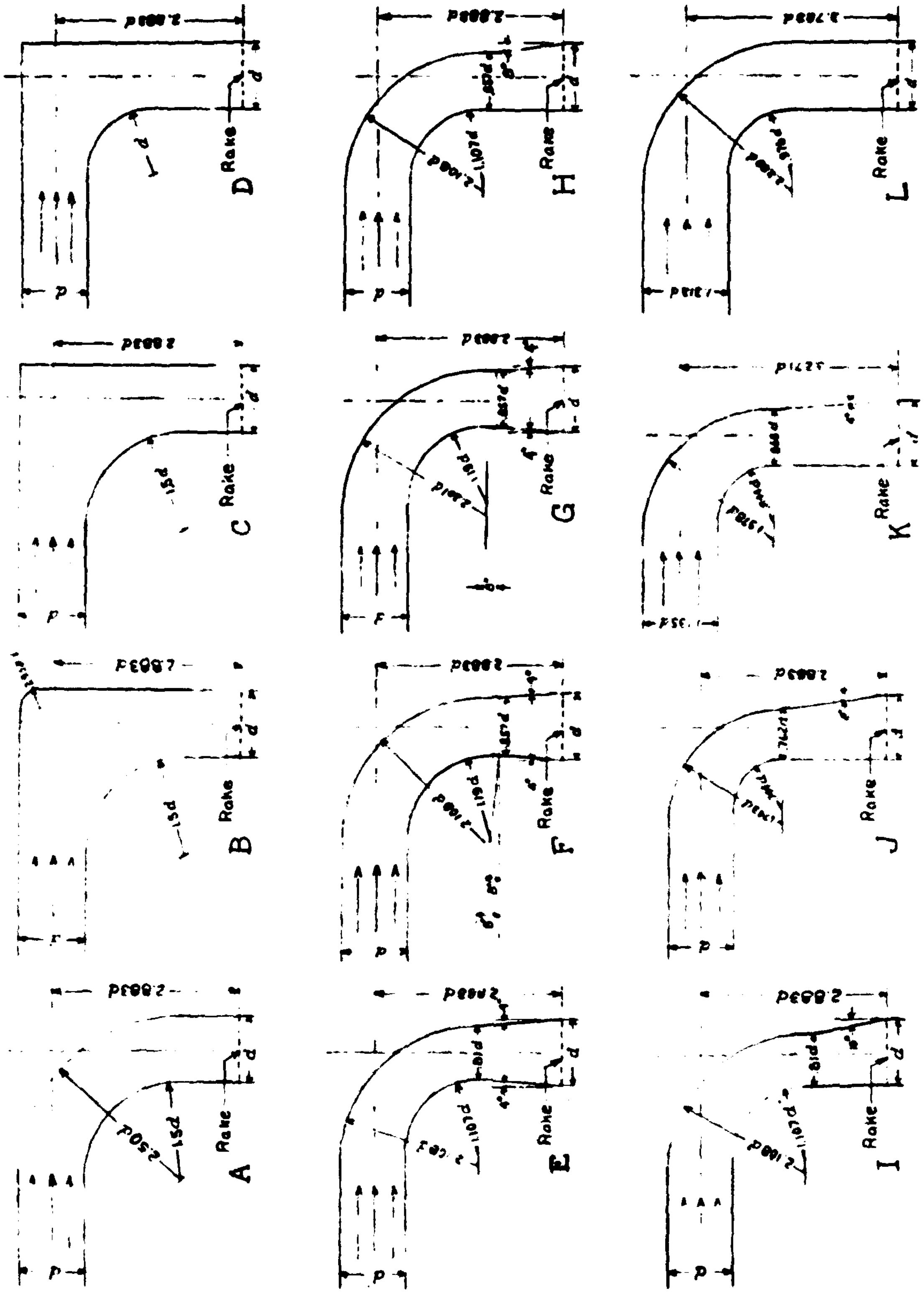

Figure 1.- Elbow forms

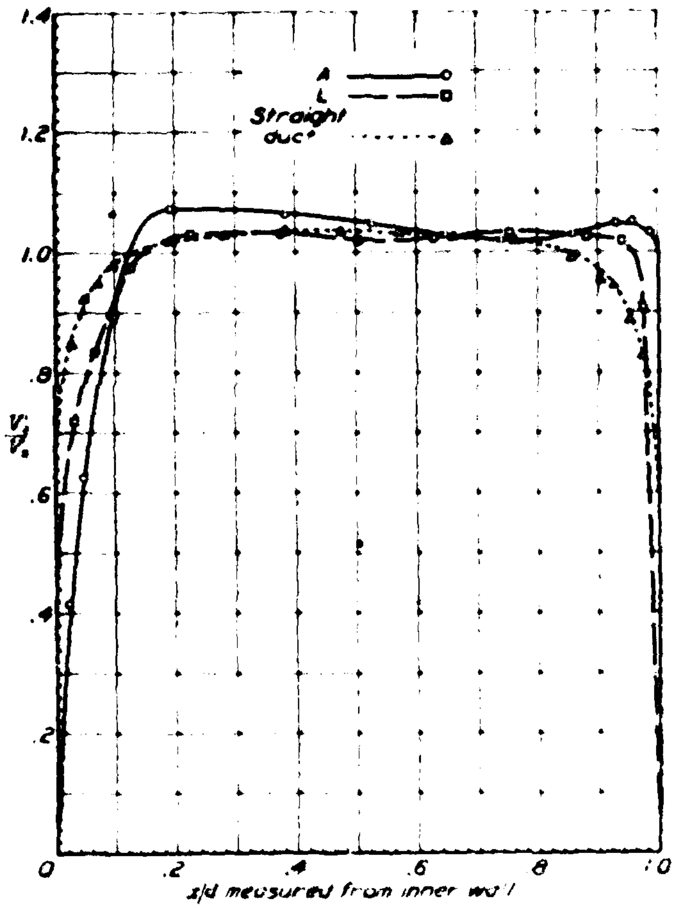

Figure 2.- Velocity distribution measured with rake.

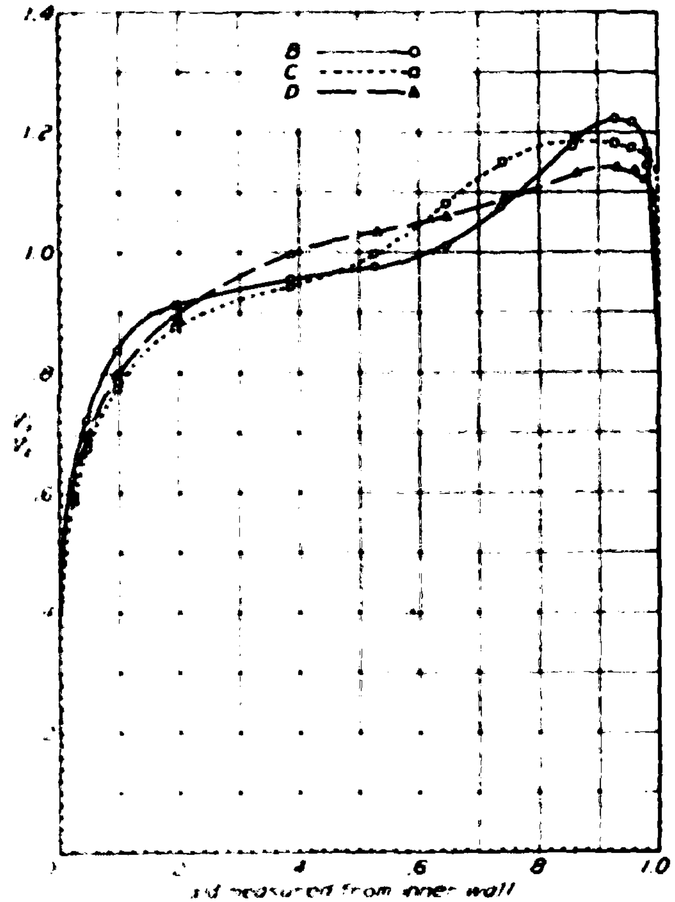

Figure 3.- Velocity distribution measured with rake.

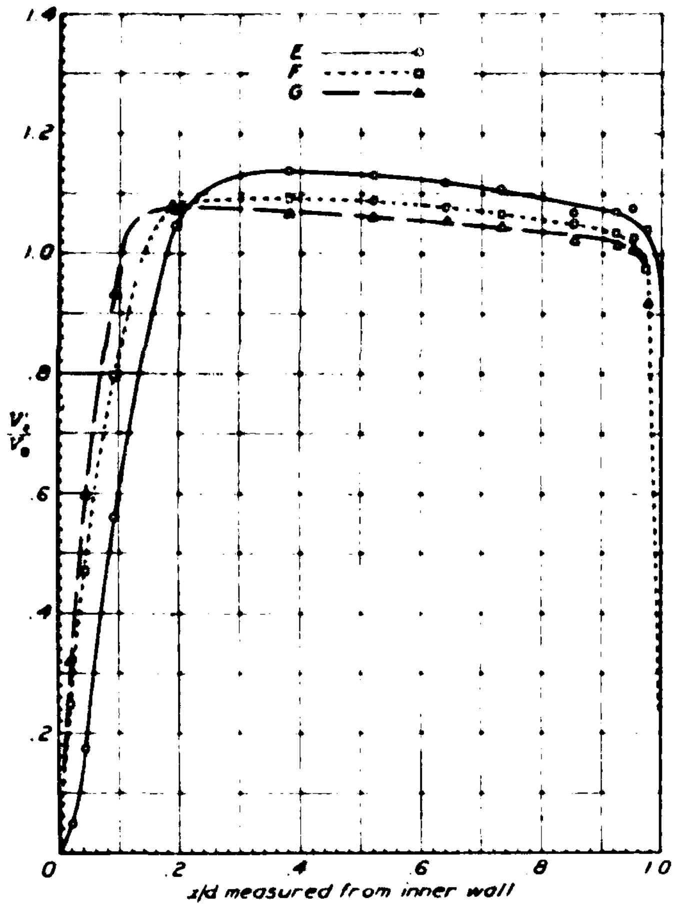

Figure 4.- Velocity distribution measured with rake.

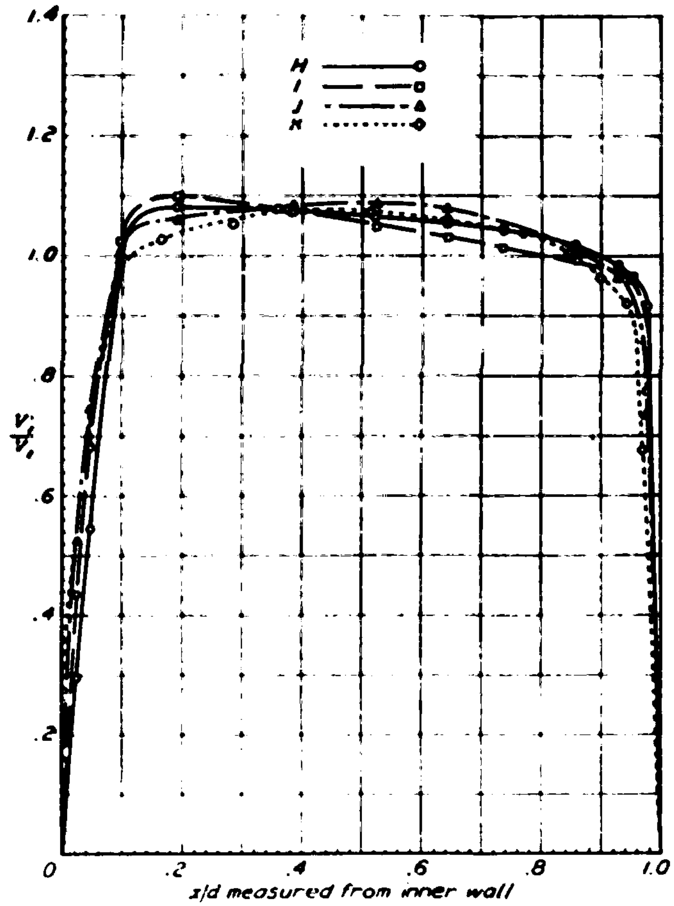

Figure 5.- Velocity distribution measured with rake.

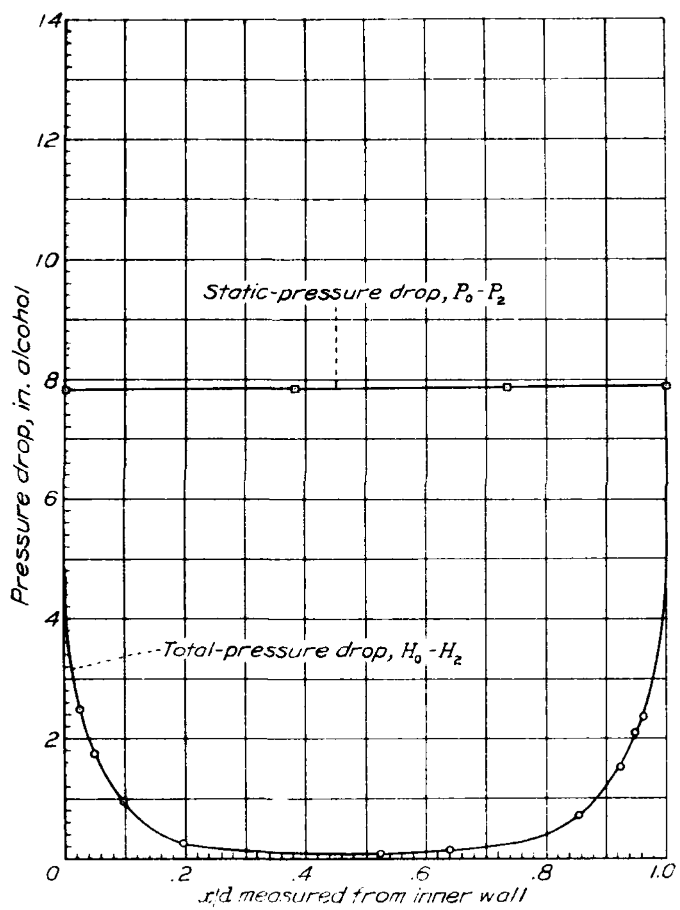

Figure 6.- Pressure distribution across duct in straight pipe. Pressure drop measured at q_2 = 6.96 inches of alcohol.

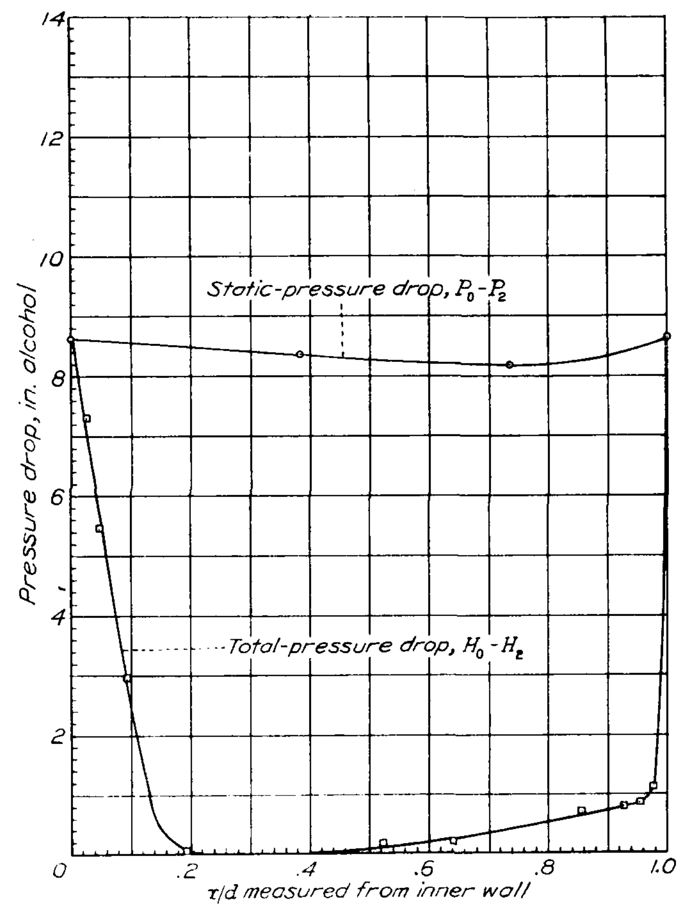

Figure 7.- Pressure distribution across duct behind elbow A. Pressure drop measured at $\bar{q}_2$ = 6.96 inches of alcohol.

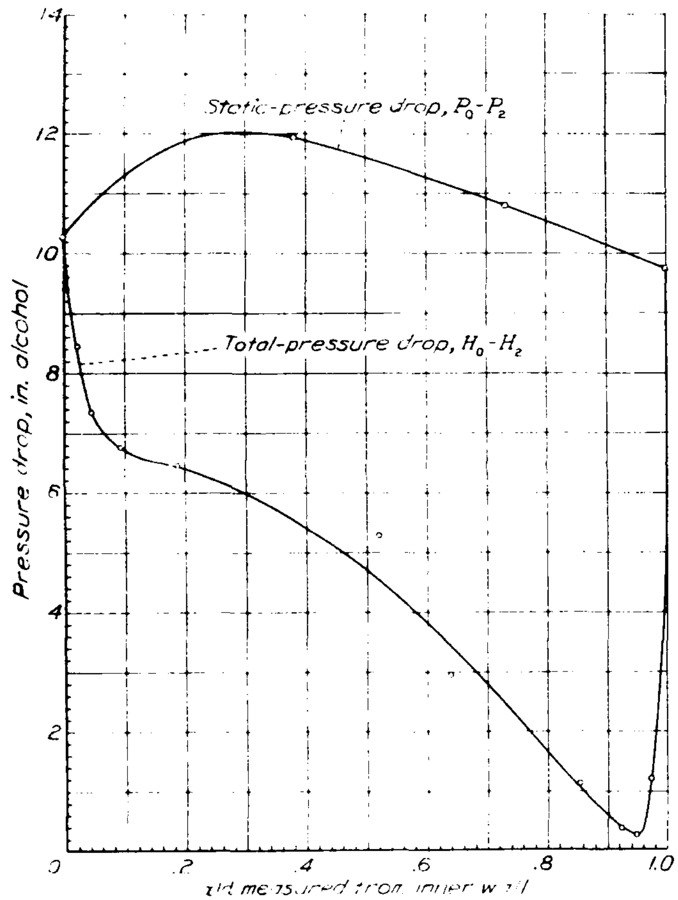

Figure 8.- Pressure distribution across duct behind elbow B. Pressure drop measured at q_2 = 6.96 inches of alcohol.

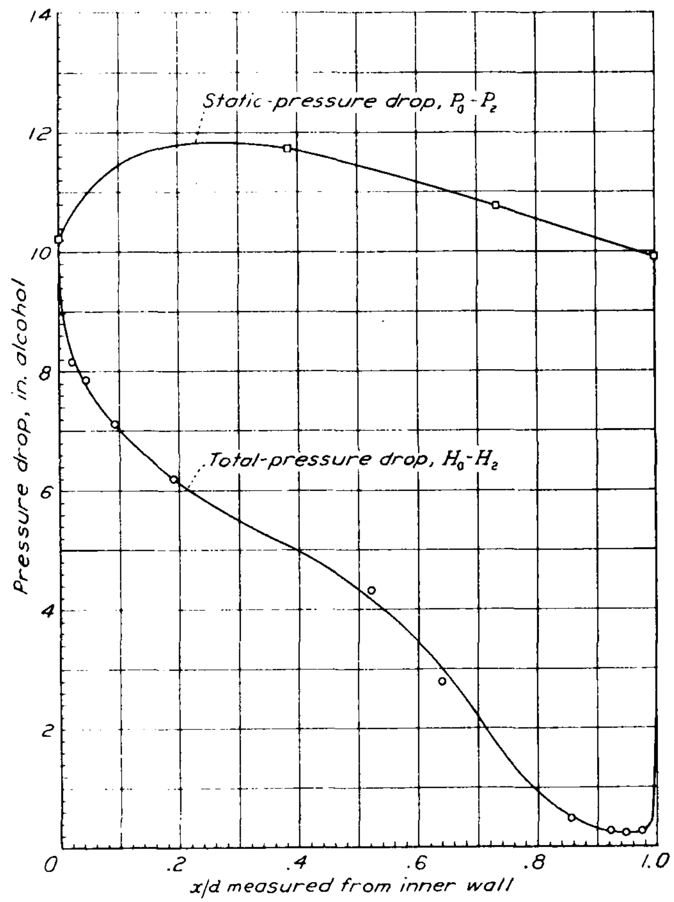

Figure 9.- Pressure distribution across duct behind elbow C. Pressure drop measured at $\bar{q}_2$ = 6.96 inches of alcohol.

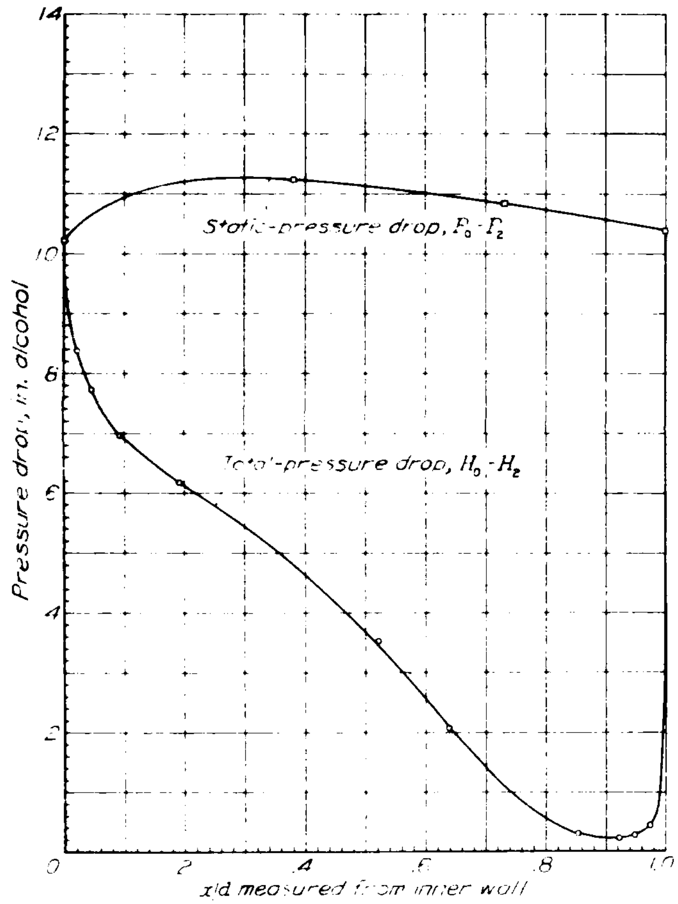

Figure 10.- Pressure distribution across duct behind elbow D. Pressure drop measured at $\bar{q}_2$ = 6.96 inches of alcohol.

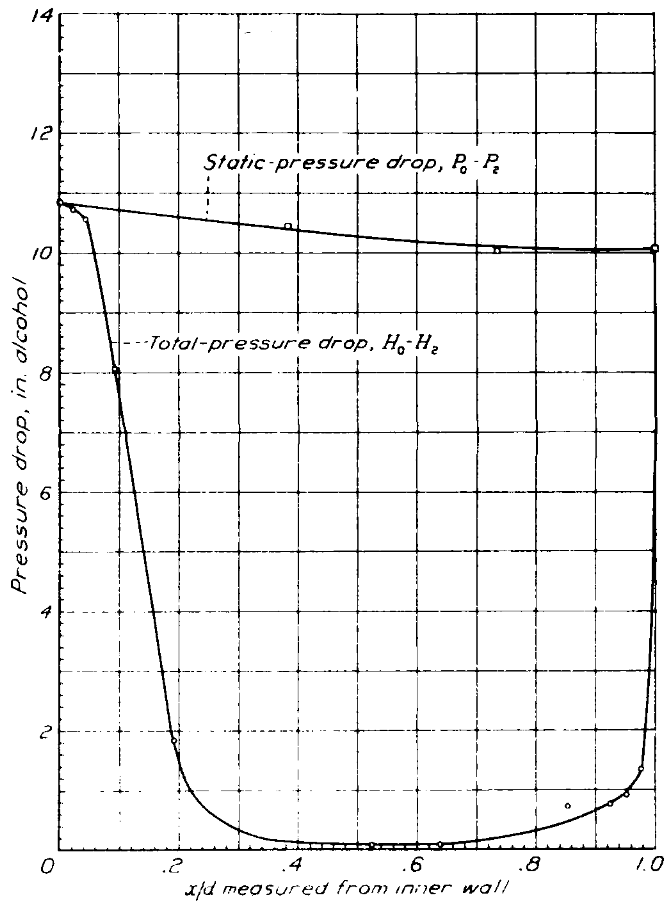

Figure 11.- Pressure distribution across duct behind elbow E. Pressure drop measured at $\bar{q}_2$ = 6.96 inches of alcohol.

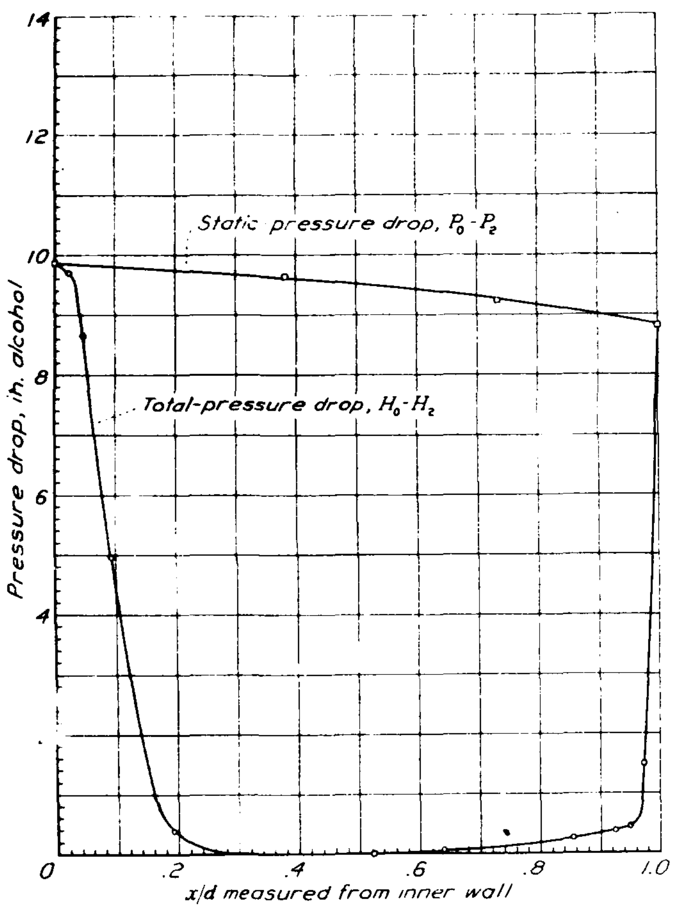

Figure 12.- Pressure distribution across duct behind elbow F. Pressure drop measured at $\bar{q}_2$ = 6.96 inches of alcohol.

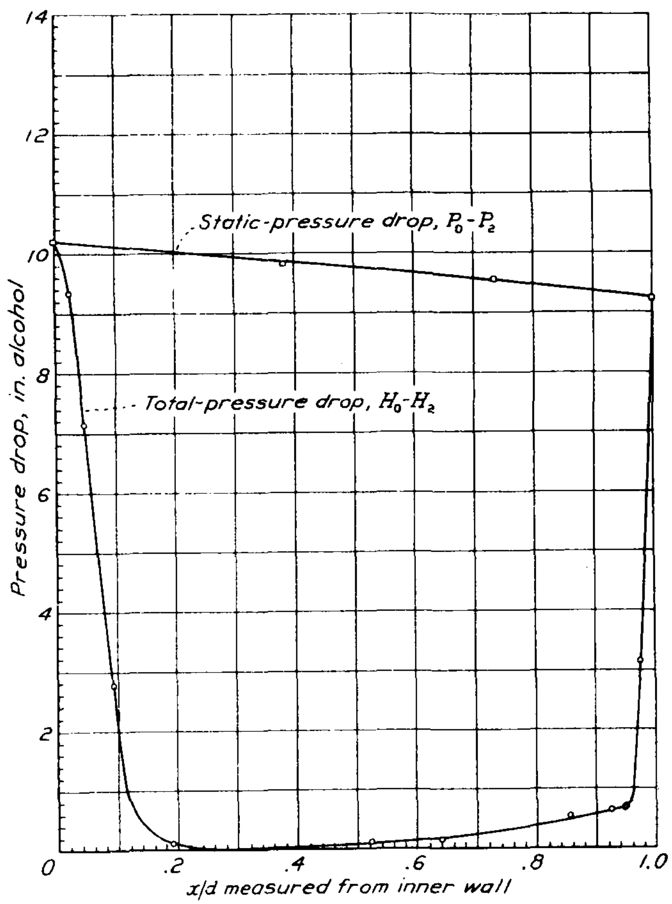

Figure 13.- Pressure distribution across duct behind elbow G. Pressure drop measured at $\bar{q}_2$ = 6.96 inches of alcohol.

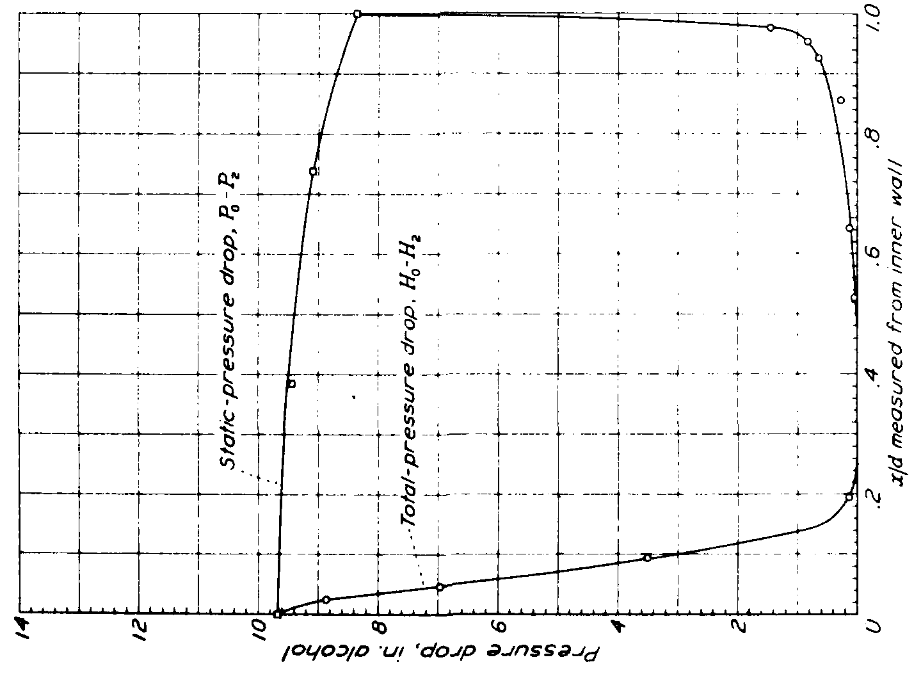

Figure 14.- Pressure distribution across duct behind elbow H. Pressure drop measured at $\bar{q}_2$ = 6.96 inches of alcohol.

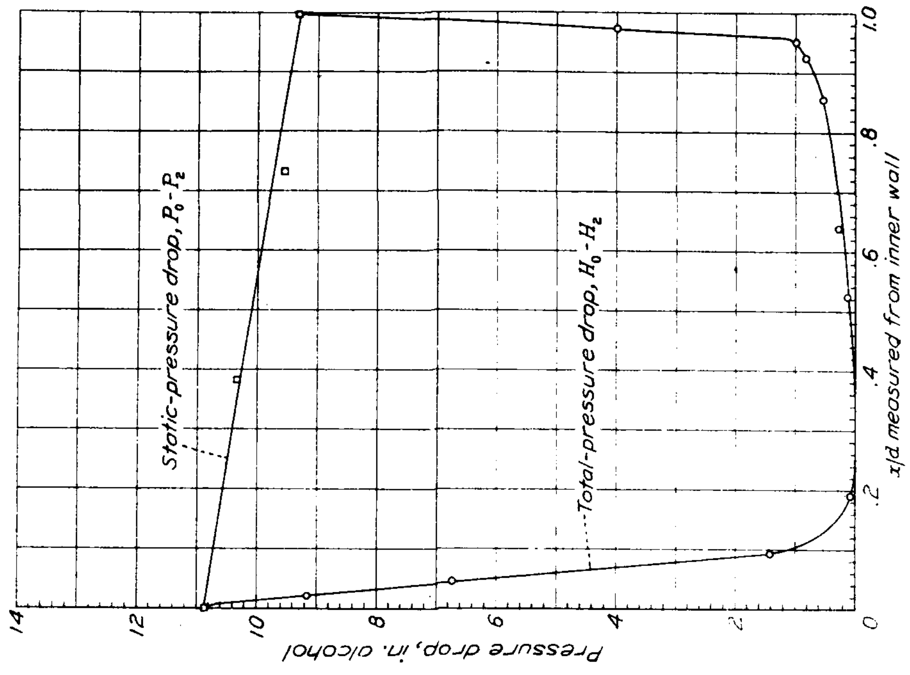

Figure 15.- Pressure distribution across duct behind elbow I. Pressure drop measured at $\bar{q}_2$ = 6.96 inches of alcohol.

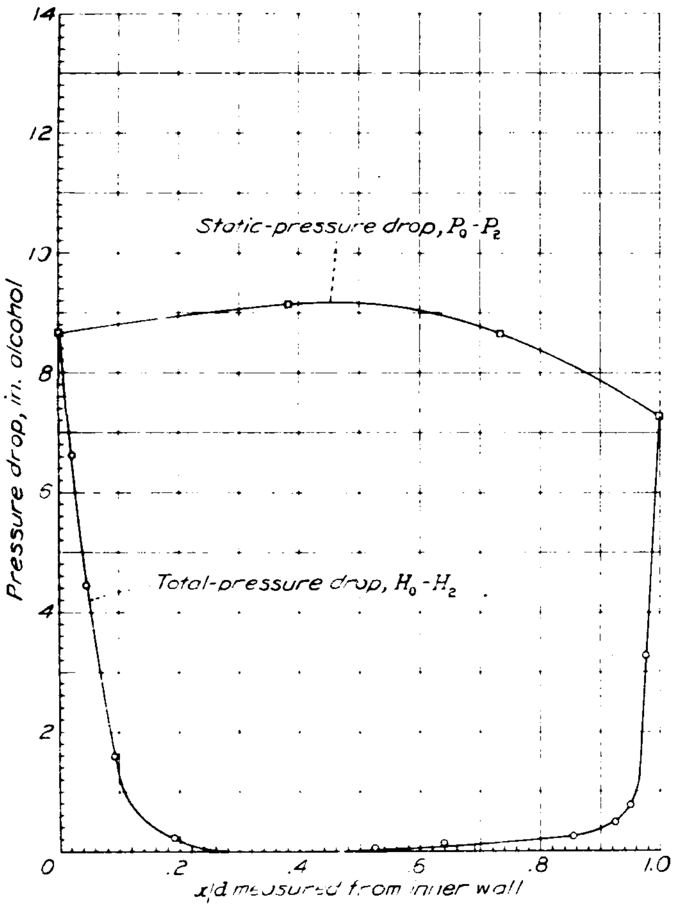

Figure 16.- Pressure distribution across duct behind elbow J. Pressure drop measured at $\bar{q}_2$ = 6.96 inches of alcohol.

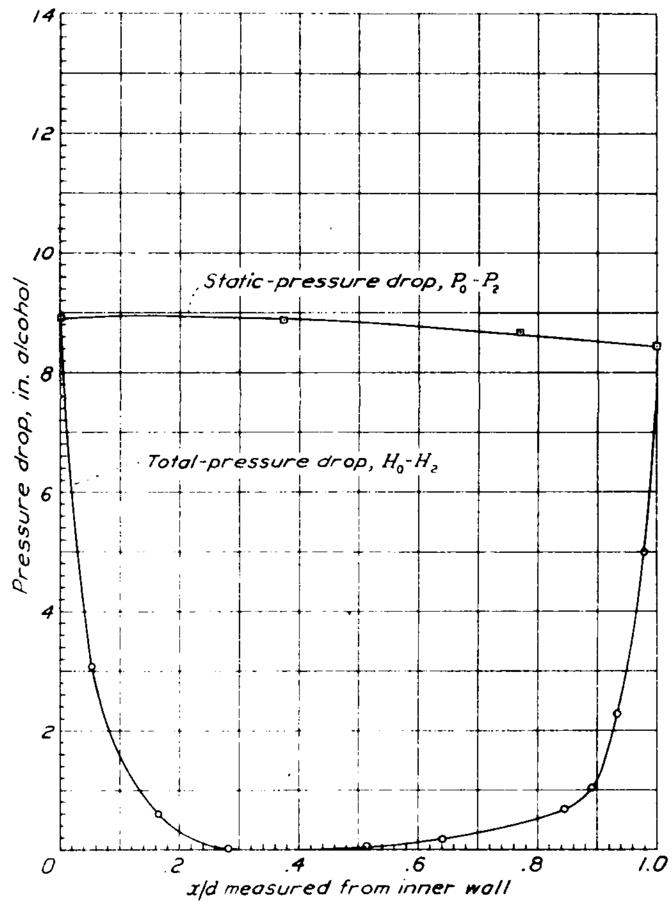

Figure 17.- Pressure distribution across duct behind elbow K. Pressure drop measured at $\bar{q}_2$ = 6.96 inches of alcohol.

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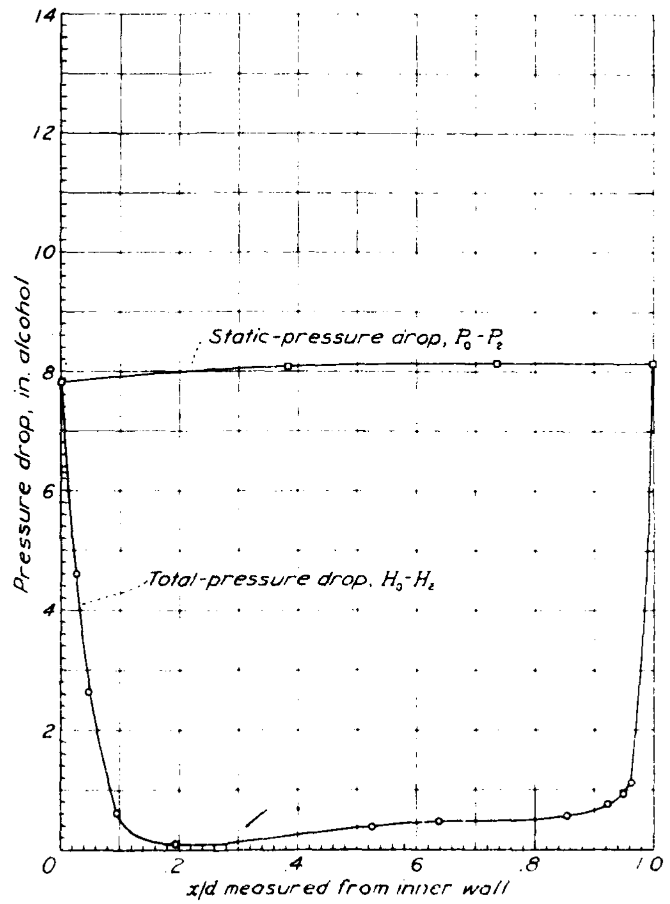

Figure 18.- Pressure distribution across duct behind elbow L. Pressure drop measured at q_2 = 6.96 inches of alcohol.

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ABSTRACT:

Development is discussed of an elbow for use in airplane carburetor air-intake ducts which have low losses and satisfactory velocity distribution without using turning vanes. Tests were conducted using a rectangular duct having width 2.57 times as great as the depth and the elbow in horizontal plane. Two characteristics of elbows were amount of flow for given pressure drop and velocity distribution across duct after bend. Elbow having smaller exit duct than entrance duct was found to have lowest losses.

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